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Analytical Models for SERVMART

Inventory Control

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ABSTRACT

Inventory policies for the control of items carried by the Naval Supply Centers at their retail self-service stores (SERVMARTS) are developed. The reorder-level, reorder-quantity procedures minimize ordering, holding and stockout costs subject to constraints on inventory investment and stockout risk.

Examples are presented for random samples from three SERVMARTS in the San Diego area and comparisons are made with two policies presently in use. The comparisons show a large reduction in the number of orders placed per year with a reduction in total system costs. Also included are recommended procedures for determining both the budget for inventory investment and the range of items carried at the SERVMARTS.

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Prepared by:

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I. INTRODUCTION

The Naval Supply Systems Command has long recognized the need for supply outlets where its customers can serve themselves to needed supplies with minimal delay. At the same time, a need to reduce the requisitioning workload at the Naval Supply Centers has become apparent. Retail self-service stores (SERVMARTS) were created to satisfy those needs. With their simplified accounting procedures and money-value (vs. line-item) transactions with customers, SERVMARTS have given to each Naval Supply Center (NSC) a means of providing efficient, economical and expeditious supply support to their customers for the relatively high-demand, low-cost items. The supermarket method of SERVMART operation results in an appreciable reduction in handling costs since each customer can satisfy his demands for multiple units of several different line items with a single requisition document, whereas requisition documents for each line item would be necessary if the demands were submitted to a Naval Supply Center.

In order to provide some guidelines as to the range and depth of items carried at the SERVMARTS, the Naval Supply Systems Command (NAVSUP) prescribed in a directive of 1967 [Ref. 1] that items carried must meet the following criteria:

(1) The unit price must be less than $250.

(2) The item must have an average monthly demand of at least two units over a 12 month period.

(3) The total average on-hand inventory value is limited to 30 days of stock. (Individual stock levels may be flexible.)

(4) No insurance, repairable, critical or classified items may be carried.

The SERVMARTS are established in close proximity to the principal customers of a parent NSC. As is evident by the following example, the volume of business conducted at the SERVMARTS can represent a significant portion of the total sales of an NSC. At NSC San Diego, approximately 18,000 line items are distributed to its twelve SERVMARTS. Those stores account for 29% of the dollar sales of Navy Stock Account materials and about 62% of the line item issues at NSC San Diego. [Ref.2].

Up to the present time, NAVSUP has not prescribed the inventory control policies for a parent NSC to follow in operating its SERVMARTS. Rather, each NSC is allowed to determine individually its own inventory control procedures according to its interpretation of the NAVSUP criteria above. The absence of official guidance has led to various inventory control procedures which, for the most part, apply uniform reorder procedures to all items in a SERVMART's inventory. Typical of those are the following very simple policies: (a) Method 1: Assuming demand is deterministic for each item, order 60 days of stock whenever the reorder level of a lead-time's demand is reached.

(b) Method 2: Order 30 days of stock whenever the reorder level of one-half a month of stock is reached. Demand for each item is again assumed to be deterministic.

Both of these policies have been structured so that the SERVMARTs meet the NAVSUP budget constraint of an average of 30 days stock investment. Because these policies treat all items the same, they are easy to implement and, consequently, appealing.

On the other hand, these policies have resulted in creating an unnecessarily large number of resupply actions which are imposing workload problems on the parent Supply Centers. Furthermore, such policies leave much room for improvement because demand histories, unit costs and other characteristics vary significantly among items.

Some attempts to consider demand rates and unit prices have resulted in simple stratification models having different procedures for determining reorder quantities across the various stratum. However, no explicit consideration is given to the uncertainty of demand, nor to the balancing of the various stockage costs. Thus, it would seem likely that constrained economic order quantity policies which explicitly consider individual item characteristics and the relevant costs could reduce total system costs while providing improved service. At the same time, such inventory control policies must not become so unwieldy that they are difficult to use or expensive to implement. That is, they must be cost-effective.

The special characteristics of the SERVMART items and, in particular, the peculiarities of the SERVMART operation lend themselves quite nicely to methods of scientific inventory control. The primary differences in the SERVMART operation and most other supply operations in the Naval Supply System may be indicated by listing some of the SERVMART characteristics:

(1) All items are relatively low-cost and of moderate to high demand.

(2) All items have the same essentiality.

(3) Procurement leadtimes for all items are very short, and alternate (though somewhat more expensive) sources of customer supply are available. These eliminate the necessity for large quantities of safety stock.

(4) An underlying goal is to expand the volume of SERVMART sales without causing a commensurate increase in the demand on resources at the NSC.

We take advantage of the special characteristics of SERVMARTS to develop two inventory models from which economic order quantities and reorder levels can be determined. We illustrate the calculations with random samples of

items from three SERVMARTS in the San Diego area. In addition, we propose methods for determining the range of items to be carried and the investment budget for each SERVMART.

II. MODEL ASSUMPTIONS AND NOTATION

Information provided by NSC San Diego led us to make the following assumptions about SERVMART operations.

(1) Procurement Leadtime: The time required to resupply a SERVMART is a constant value γ for all items carried at the given SERVMART. (The value may vary across SERVMARTS). Furthermore, γ is so short that, for each item, the probability of two or more resupply orders outstanding concurrently is zero. (Since the source of resupply is either the parent NSC or a local business which maintains reserve stocks, leadtimes are usually less than one week.)

(2) Unit Costs: The cost of each unit of an item ordered by a SERVMART is independent of the quantity ordered. We denote the constant unit cost of item i by C_i .

(3) Holding Cost Rate: The inventory carrying cost rate is the same value I for all items at a SERVMART. Although handling and storage requirements may differ among items, any difference in holding rates is probably insignificant. This is particularly true because items needing special attention are, for the most part, excluded from SERVMART inventories by the NAVSUP directive.

(4) Essentiality: All items have the same essentiality .

(5) Inventory Review: Stock assets are reviewed continuously.

(6) Demand Distributions; The total leadtime demand for item i is normally distributed with mean μ_i and standard deviation σ_i .

(7) Lost Sales and Fixed Ordering Costs: The fixed ordering costs are the same for all items at a SERVMART. Let A be the "average" fixed cost on the system when a SERVMART submits a replenishment order to the

parent NSC for units of a single line item. This cost includes such factors as:

(a) Cost of SERVMART personnel to determine a need for replenishment and to prepare the requisition document.

(b) Cost of storage of material upon receipt at the SERVMART.

(c) Cost of civilian personnel at the parent NSC to process the requisition and to prepare the material for delivery to the SERVMART.

(d) Data-processing costs for the requisition.

(e) Cost of transporting the material from the parent NSC to the SERVMART.

Similarly, let A_c be the average fixed cost at the NSC to fill one customer (non-SERVMART) line item requisition. This cost includes factors (c), (d), and (e) above with the modification that material is delivered directly to the customer.

Lastly, let A_s be the average fixed cost to the system of filling a customer demand for units for a single line item at the SERVMART. Factors included in A_s are the total civilian personnel costs for operating the SERVMART plus all data-processing costs associated with the SERVMART exclusive of those resulting from requisitioning and the total requisitioning costs imposed on the system because of orders placed by the SERVMART at the parent NSC. To obtain A_s, the total costs are divided by the total number of line item issues filled by the SERVMART.

The magnitude of A_s is substantially smaller than the value of A_c. For example, NSC San Diego uses a figure greater than $6.00 for A_c, while its SERVMARTS use a value less than $1.00 for A_s. This difference in A_s and A_c provides probably the strongest economic justification for the establishment of SERVMARTS. Demands which cannot be filled by a SERVMART are not backordered because alternative sources of supply are so readily

available to the customer. However, the supply system does suffer whenever the SERVMART fails to completely satisfy a customer's demand for units of a given line item which it normally carries. This is because the customer must then submit a requisition to the NSC. The normal savings to the system, $A_c - A_s$, must be foregone whenever this occurs. It is exactly the "lost savings" that we take to be the cost of each item demand which the SERVMART cannot satisfy. We denote the "lost-sales" cost by π.

Note that the system suffers no penalty if a customer merely postpones picking up items which are not available, or if he obtains the units at another SERVMART. Although there may be some cost to the Navy because of delays, no requisition is submitted to the parent NSC, and, in fact, the Supply System may not even be aware that a customer was unsatisfied.

Among the model assumptions, that about the distribution of demand is probably the weakest. There is not sufficient SERVMART data from which demand distributions can be obtained or tested. Nevertheless, the use of the normal distribution is consistent with present Navy regulations for moderate to high demand items, and the normal distribution often provides adequate approximations to other distributions which might be appropriate such as the Poisson, compound Poisson or negative binomial. In any case, its use should surely provide an improvement over the use of deterministic demand.

III. MATHEMATICAL MODELS

Although the SERVMARTS have characteristics which distinguish them from other sources of supply, economic factors must still play a prominent role. Indeed, economic order policies which attempt to minimize total expected system costs seem to be entirely appropriate for SERVMART operations, especially since the cost of a lost sale can be quantified. However, to insure that the dollar investment in inventory not exceed the amount allowed, we must constrain the order quantities and the reorder levels.

The simple inventory control policies which attempt to stock an average of 30 days demand for each item create a large number of resupply actions. This, in turn, imposes workload problems at both the SERVMART and the parent NSC and often results in reduced service. Thus, it might seem appropriate to impose a constraint on the number of SERVMART resupply actions. However, a single SERVMART resupply action will probably fulfill many relatively inexpensive demands from customers who would have otherwise placed direct orders at the parent NSC, thereby increasing its workload many-fold. Hence, it seems inconsistent with the establishment of SERVMARTS to place a constraint on the number of SERVMART resupply actions, provided economic order policies which consider total system costs are being used.

In the following section, we determine expressions for those order quantities and reorder levels which minimize total expected ordering, holding and lost-sales costs subject to a constraint on the total amount of money available for inventory investment.

A. MODEL I

We seek to determine the sum of the ordering, holding and stockout costs per year for all items carried by a given SERVMART. Because of the stochastic nature of demand and the absence of information about the processes generating demand, the cost expressions which we derive will, of necessity, be approximations to the actual costs experienced. Nevertheless, the approximations are realistic, and we feel that they will provide a good indication of real costs.

(1) Ordering Cost:

The policies that we consider order a fixed quantity Q_i as soon as the on-hand inventory for item i hits or falls below a fixed level r_i. If λ_i denotes the average number of units of item i demanded per year, then the mean number of orders placed per year is λ_i/Q_i, and the mean

ordering cost per year (exclusive of the price of the units themselves) is $\lambda_i A/Q_i$.

(2) Lost Sales Cost:

The average number of lost sales per year is simply the average number of lost sales per order cycle multiplied by the average number of orders per year. Let μ_i and σ_i be the mean and standard deviation, respectively, of lead time demand, and let $f(\cdot)$ and $F(\cdot)$ be the probability density function and distribution function, respectively, of a standard normal random variable. We show in Appendix A that the expected number of lost sales per cycle is

$$W_i(r_i) = (\mu_i - r_i)\left(1 - F\left(\frac{r_i - \mu_i}{\sigma_i}\right)\right) + \sigma_i f\left(\frac{r_i - \mu_i}{\sigma_i}\right)$$

Let M_i be the average number of units per customer demand for item i . Then, the expected lost sales cost per year for item i is approximated by

$$\pi \frac{\lambda_i}{Q_i} \cdot \frac{W_i(r_i)}{M_i}$$

(3) Holding Cost:

Because of random demands and positive leadtimes, the stock on hand when a shipment arrives is a random quantity varying between r and 0. To provide protection against stockouts, it is necessary to carry some extra stock over that amount normally needed to satisfy demands during a leadtime. Let S_i denote the expected value of this buffer stock. The expected on-hand inventory then varies between $S_i + Q_i$ and S_i . We approximate the mean value of the on-hand inventory by the simple average of $S_i + Q_i$ and S_i , $S_i + Q_i/2$. It is shown in Appendix A that

$$S_i = r_i - \mu_i + W_i(r_i) .$$

From this, we obtain the average annual inventory holding cost to be

$$IC_i[r_i + \frac{Q_i}{2} - \mu_i + W_i(r_i)] \ .$$

(4) Total Annual Cost

Combining the ordering costs, lost sales costs and holding costs for all N items carried by the SERVMART, we get for the total annual cost:

$$(1.1) \qquad K = \sum_{i=1}^{N} [\frac{\lambda_i A}{Q_i} + IC_i(r_i + \frac{Q_i}{2} - \mu_i + W_i(r_i)) + \frac{\pi\lambda_i}{Q_i}\frac{W_i(r_i)}{M_i}]$$

Were it not for the constraint on the budget available for inventory investment, the optimal choices of the r_i's and Q_i's would be given by finding those values which minimize K. However, the budget constraint imposes a dependence between items because all items must compete for the same investment dollars. Hence, we must add the constraint on average inventory investment. If B_o is the upper limit on average inventory investment, the constraint is written mathematically as

$$(1.2) \qquad \sum_{i=1}^{N} C_i(r_i + \frac{Q_i}{2} - \mu_i + W_i(r_i)) \le B_o$$

We use the Lagrange multiplier technique to solve for the optimal values of the r_i's and the Q_i's in this constrained minimization problem. The mathematical derivations of the formulae are presented in Appendix A. The expressions determined are:

$$(1.3) \qquad Q_i = \left(\frac{2\lambda_i(A + \pi \frac{W_i(r_i)}{M_i})}{(I + \Theta)C_i} \right)^{1/2} \qquad i = 1, 2, \ldots, N$$

and

$$(1.4) \qquad 1 - F\left(\frac{r_i - \mu_i}{\sigma_i}\right) = \frac{(I + \Theta)C_iQ_i}{(I + \Theta)C_iQ_i + \frac{\pi\lambda_i}{M_i}} \qquad i = 1, 2, \ldots, N$$

where Θ is the Lagrange multiplier, the value of which must be manipulated so that the constraint is not violated. Unfortunately, (1.3) and (1.4) cannot be solved explicitly for r_i and Q_i. Hence, it is necessary to solve iteratively for r_i and Q_i while simultaneously adjusting the value of Θ to satisfy the inventory investment constraint. The iterative procedure is as follows:

(a) Set $\Theta = 0$.

(b) Set $Q_i = \left(\frac{2\lambda_i A}{(I+\Theta)C_i}\right)^{1/2}$

(c) Use Q_i in (1.4) to determine r_i.

(d) Use the r_i from (c) in (1.3) to determine a new value for Q_i.

(e) Repeat steps (c) and (d) until the values of r_i and Q_i are obtained with sufficient accuracy. Since we are only interested in integer values of r_i and Q_i, we round off and stop when new values of r_i and Q_i are the same as previous values.

(f) Calculate $\sum_{i=1}^{N} C_i \left(\frac{Q_i}{2} + r_i - \mu_i + W_i(r_i)\right) = B$.

(g) If $B > B_0$, increase Θ and return to step (b). If $B < B_0$, decrease Θ and return to step (b). Continue adjusting Θ until B is sufficiently close to B_0. If $B < B_0$ when $\Theta = 0$, the constraint is not active and the iterative search

is concluded.

It can be shown that the solutions for r_i and Q_i from (1.3) and (1.4) always exist, and they are unique. Furthermore, the convergence of the iterative scheme can be proved. (For details see [Ref. 3, pp. 170,171].) In practice, the convergence is usually quite rapid, and, while somewhat involved, the entire procedure usually requires very little computer time. For example, less than ten seconds of computer time on the Naval Postgraduate School IBM 360/67 were needed to determine all r_i's and Q_i's for a 200 item sample at one SERVMART in San Diego. The computer program used to determine the reorder parameters is presented in Appendix B. Examples of the calculations from three SERVMARTs in the San Diego area are presented in a later section.

B. MODEL 2

The determination of the optimal values of r_i and Q_i in the preceding inventory model could be somewhat tedious because of the need to adjust the value of the Lagrange multiplier while solving for r_i and Q_i iteratively. Although the computer requirements in terms of time and memory were not significant in the sample runs that we made, they may become critical if the number of items carried at a given SERVMART is very large or if the available computer facilities are less sophisticated than the system we used. For these reasons, a second model was developed. Model 2 produces explicit closed-form solutions thus eliminating the need to iterate to determine the optimal reorder levels and reorder quantities.

In all inventory systems reorder levels are determined so that protection is provided against stockouts during the leadtime. In many models the desirable stockout protection is expressed implicitly by the cost of lost sales or backorders. However, inventory managers often override calculated reorder levels by specifying given minimal levels of stockout protection. This override is usually stated as a maximum acceptable stockout probability. Model 2 allows

for exactly such a restriction. The formulation follows:

$$\text{(1.5)} \qquad \text{Min } K = \sum_{i=1}^{N} \left[\frac{A\lambda_i}{Q_i} + IC_i\left(\frac{Q_i}{2} + r_i - \mu_i + W_i(r_i)\right) + \frac{\pi\lambda_i W_i(r_i)}{Q_i M_i} \right]$$

subject to

$$\text{(1.6)} \qquad \sum_{i=1}^{N} C_i\left(\frac{Q_i}{2} + r_i - \mu_i + W_i(r_i)\right) \le B_Q$$

and

$$\text{(1.7)} \qquad \text{Prob}\left[X_i \le r_i\right] = p \quad \text{for all } i \text{ ,}$$

where X_i is the random leadtime demand for item i.

Equation (1.7) is an explicit statement about the acceptable risk of a stockout for an item. This constraint imputes a lost sales cost, and, for this reason, it is somewhat redundant because the lost sales cost is already included in (1.5). One effect is to change the cost of a lost sale. If the consequences of rounding the reorder levels to integer values are neglected, another effect of (1.7) is to force uniform protection for all items. This contrasts with the situation in Model 1 where the safety levels can vary depending on the individual item characteristics. Thus, (1.7) allows the inventory manager to exert additional control over the safety stock, and, more importantly, it provides a means of determining the values of r_i independent of Q_i.

The value for r_i was solved directly from (1.7) to yield

$$(1.8) \quad r_i = \mu_i + \sigma_i Z_p ,$$

where Z_p is the p^{th} percentile of the standard normal probability distribution.

The Lagrange technique was used to solve for the optimal value of Q_i. The calculations were similar to those required by Model 1 and, consequently, are not repeated. The result is:

$$(1.9) \quad Q_i = \frac{2\left(\frac{\lambda_i}{C_i}\right)^{1/2} \left[\left(A + \pi \frac{W_i(r_i)}{M_i}\right)^{1/2} \left[B_o + \sum_{i=1}^{N} C_i(\mu_i - r_i - W_i(r_i))\right]\right]}{\sum_{i=1}^{N} \left[C_i \lambda_i \left(A + \frac{\pi W_i(r_i)}{M_i}\right)\right]^{1/2}}$$

The formulation of Model 2 eliminates both the need to iterate for the reorder levels and the reorder quantities and the need to search for the value of Θ. In fact, neither the value for I , nor Θ , appear in the equations for r_i and Q_i. Thus, a value for I is unnecessary, and the only costs needed are π, A and C_i. The amount of computation is reduced significantly over that required by Model 1.

As discussed earlier, the choice of p is left to the discretion of the SERVMART manager. Because leadtimes are so short, high levels of stockout protection can usually be achieved with relatively small reorder levels. Hence the buffer stock accounts for only a minute portion of the inventory investment and the inventory holding costs. Furthermore, the existence of nearby alternative sources of supply reduces somewhat

the importance of stockout protection. Indeed, as far as total system costs are concerned, the reorder quantities assume, by far, the more important role since the primary raison d'etre of a SERVMART is to decrease total requisition costs. Nevertheless, the reorder quantities depend on the reorder levels which are determined by p. Hence care should be taken in selecting the value of p. An appropriate criterion for choosing p would seem to be to choose a value which yields results comparable to those given by Model I. A random sample from one SERVMART should suffice to determine a value of p to be used in the calculations of the reorder levels for all SERVMARTS.

IV. SERVEMART RANGE DETERMINATION

We have discussed two models for calculating the reorder quantity and the reorder level for each item which is carried by a SERVMART. Probably just as important is the question, "what items should be carried?" The NAVSUP directive provides some guidance by restricting those items carried to have a unit price less than $250 and to have an average monthly demand of at least two units over a 12 month period. Furthermore, no insurance, repairable, critical or classified items can be carried by a SERVMART. Nonetheless, further guidance is needed, and other economic factors should be considered before carrying an item at a SERVMART.

The primary economic justification for carrying an item at a SERVMART is the savings which results from the decreased costs of filling customer's demands. Therefore, it is logical that the "stock or no-stock" decision should be based on the cost of filling customer's demands at the SERVMART compared to the cost of filling those same demands at the NSC. This, in turn, is influenced by the number of customer demands at the SERVMART and the average quantity demanded per customer. An illustrative example points out the relative costs involved.

Example 4.1: Let $A_s = \$1.00$, $A_c = \$6.50$ and $A = \$9.00$. Item 1 has a mean annual demand of $\lambda_1 = 150$ units, an economic order quantity of

$Q_1 = 75$ units and an average demand size per customer of $M_1 = 50$ units. The average number of customer requisitions for the item filled by the SERVMART each year is λ_1/M_1 , while the average number of SERVMART requisitions filled by NSC is λ_1/Q_1 per year. Thus the total average cost to the system of filling demands for line item 1, if carried at the SERVMART, is

$$\frac{\lambda_1}{M_1} A_s + \frac{\lambda_1}{Q_1} A = (3)(1) + (2)(9) = \$21 \text{ per year.}$$

The comparable figure if the item were carried only by the NSC is

$$\frac{\lambda_1}{M_1} A_c = (3)(6.50) = \$19.50 \text{ per year.}$$

Thus, the item should not be carried at a SERVMART. On the other hand, if M_1 were 10 units, the cost breakdown would be:

(i) Carried at a SERVMART: $\frac{\lambda_i}{M_i} A_s + \frac{\lambda_i}{Q_i} A = \$33$ per year.

(ii) Carried only by NSC: $\frac{\lambda_i}{M_i} A_c = \$97.50$ per year.

In this case, it is more economical to carry the item at a SERVMART.

The example points out the importance of considering the average quantity per line item demand in determining the range of SERVMART stock. The example is easily generalized to obtain a criterion for choosing those stocks to be carried at a SERVMART.

STOCKING RULE: An item carried at a Naval Supply Center should be carried at a SERVMART if, and only if, the item satisfies all properties required by the NAVSUP directive and

$$\frac{\lambda_i}{M_i} A_s + \frac{\lambda_i}{Q_i} A < \frac{\lambda_i}{M_i} A_c ,$$

or, equivalently,

$$(4.1) \qquad \frac{Q_i}{M_i} > \frac{A}{A_c - A_s} .$$

It is interesting to note that the stocking rule (4.1) does not explicitly involve either the unit cost of the item or its frequency of demand λ_i. These factors are involved, however, in the determination of Q_i. Since the optimal SERVMART reorder quantity, Q_i, for an item not stocked at the SERVMART is unknown, the value for Q_i must be approximated. The simple EOQ formula

$$(4.2) \qquad Q_i = \left(\frac{2\lambda_i A}{(I+\Theta)C_i} \right)^{1/2}$$

should suffice.

The stocking criterion can also be used to rank items according to potential cost savings. Such a ranking might be useful if investment budgets are too tight to allow all "qualified" items to be included in the SERVMART's inventory. If item i qualifies as a "stock" item, the expected annual system savings for item i is

$$(4.3) \qquad \lambda_i \left[\frac{A_c - A_s}{M_i} - \frac{A}{Q_i} \right] .$$

The items carried at the SERVMART should be the ones which offer the greatest savings, (4.3), to the system.

V. EXAMPLES AND COMPARISON OF MODELS

We illustrate the determination of reorder quantities and reorder levels using both Model 1 and Model 2 applied to SERVMART data from NSC San Diego. The total populations of SERVMART C (150 items) and SERVMART L (122 items) were considered along with a random sample of 200 items out of a population of 2886 items from SERVMART J. In addition, for comparison, the reorder levels and reorder quantities were determined using Method 1, the policy which orders 60 days stock whenever the stock on hand falls to a level amounting to the average leadtime demand, and Method 2, the policy which orders 30 days of stock whenever the on-hand inventory falls to 15 days of stock. The two simple policies are both driven by the NAVSUP requirement that the average inventory investment not exceed 30 days of stock. Both Model 1 and Model 2 also satisfy that constraint, but the driving factor in our models is the minimization of total system costs.

A summary of the results is presented for selected items at SERVMART J in Table 1. For each selected item, the unit price and the average annual demand are depicted along with the reorder quantity, the reorder level and the average number of orders per year for each of the four inventory policies. In addition summary data for the entire 200 item sample are included which give the reorder workload and system costs.

Table 2 displays a more complete comparison of the models. Total orders per year, average inventory investment, inventory holding cost, total lost sales cost, total system cost and the imputed holding rate are given for each SERVMART/model combination.

The results show that the economic-order-quantity (EOQ) models, developed in this paper, produce significantly fewer SERVMART orders per year than do either of the two simple policies, Method 1 and Method 2. Consequently, the requisition workload and system requisition costs are also reduced. In fact, although holding costs are slightly higher in the EOQ models and lost sales

SERVMART J

ITEM	C	λ	METHOD 1 Q	METHOD 1 R	METHOD 1 ORDERS	METHOD 2 Q	METHOD 2 R	METHOD 2 ORDERS	MODEL 1 Q	MODEL 1 R	MODEL 1 ORDERS	MODEL 1 P	MODEL 2 (p=0.82) Q	MODEL 2 (p=0.82) R	MODEL 2 (p=0.82) ORDERS
1	15.76	278	46	6	6.0	23	12	12.0	12	8	23.2	0.85	11	8	25.3
2	3.00	672	112	14	6.0	56	29	12.0	41	19	16.4	0.94	42	17	16.0
3	1.15	902	150	19	6.0	75	38	12.0	76	26	11.9	0.97	80	22	11.3
4	0.51	1392	232	28	6.0	116	58	12.0	141	39	9.9	0.98	154	33	9.0
5	3.50	119	19	3	6.2	9	5	13.1	16	4	7.4	0.86	15	4	7.9
6	10.40	32	5	1	6.4	2	2	16.0	5	1	6.4	0.67	4	2	8.0
7	1.61	176	29	4	6.1	14	8	12.6	28	6	6.3	0.91	28	6	6.3
8	0.20	1044	174	21	6.0	87	44	12.0	194	31	5.4	0.99	209	26	5.0
9	6.65	26	4	1	6.0	2	2	13.0	5	1	5.2	0.75	5	2	5.2
10	0.35	436	72	9	6.1	36	19	12.2	95	15	4.6	0.98	98	12	4.4
11	2.58	50	8	1	6.3	4	3	12.5	12	2	4.2	0.84	11	2	4.5
12	1.39	76	12	2	6.3	6	4	12.7	20	3	3.8	0.88	19	3	4.0
13	0.06	1194	198	24	6.0	99	50	12.2	378	36	3.2	0.99	412	29	2.9
14	1.96	28	4	1	7.0	2	2	14.0	10	2	2.8	0.97	9	2	3.1
15	0.90	44	7	1	6.3	3	2	14.7	19	2	2.3	0.88	18	2	2.4
16	0.13	252	41	6	6.1	20	11	12.6	118	10	2.1	0.99	120	8	2.1
17	0.03	288	48	6	6.0	24	12	12.0	262	12	1.1	0.99	269	8	1.1
18	0.14	56	9	2	6.2	4	3	14.0	53	3	1.1	0.96	53	3	1.1
19	0.26	26	4	1	6.5	2	2	13.0	27	2	1.0	0.98	26	2	1.0
20	0.08	54	9	2	6.0	4	3	13.5	69	3	0.8	0.97	68	3	0.8
TOTAL ORDERS/YEAR			1272			2468			747				784		
AVE. INVENTORY INVEST.			$3105			$2727			$3257				$3308		
TOTAL LOST SALES COST			—			—			$ 334				$ 432		
TOTAL SYSTEM COSTS			$13647			$25503			$8780				$9265		
INPUTED HOLDING RATE			—			—			2.80				3.01		

TABLE 1

MODEL COMPARISONS

	SERVMART J	SERVMART C	SERVMART L
Total Orders/Year			
Method 1	1272	949	755
Method 2	2468	1739	1426
Model 1	747	664	430
Model 2 (p = 0.82)	784	803	482
Average Inventory Investment			
Method 1	$3105	$4128	$3686
Method 2	$2727	$4588	$3566
Model 1	$3257	$4452	$4031
Model 2 (p = 0.82)	$3308	$5166	$4316
Inventory Holding Cost (I = 0.3)			
Method 1	$ 931	$1238	$1106
Method 2	$ 818	$1377	$1070
Model 1	$ 977	$1236	$1209
Model 2 (p = 0.82)	$ 992	$1559	$1295
Total Lost Sales Cost			
Method 1	-----	-----	-----
Method 2	-----	-----	-----
Model 1	$ 334	$ 409	$ 244
Model 2 (p = 0.82)	$ 432	$ 237	$ 139
Total System Cost			
Method 1	$13647	$10728	$ 8653
Method 2	$25503	$18766	$15334
Model 1	$ 8780	$ 8388	$ 5753
Model 2 (p = 0.82)	$ 9265	$ 9813	$ 6756
Imputed Holding Rate			
Model 1	2.80	1.83	1.30
Model 2 (p = 0.82)	3.01	2.51	1.55

TABLE 2

costs are included, Models 1 and 2 yield reductions in total annual system costs which range from 20% to 75% over the costs incurred by the current policies. Since all policies attempt to maintain an average inventory investment of 30 days stock, or less, there is relatively little difference in inventory holding costs.

For lack of appropriate data, the average customer demand size, M_i, was arbitrarily chosen to be unity in all examples. Therefore, the correct values for the reorder quantities might be slightly lower than the values listed, and the cost comparisons will not be entirely correct. Nonetheless, the magnitude of the error would not be large enough to change significantly the range of percentage cost reduction which was observed. The value of M_i has only a very small effect on Q_i, but M_i is an important factor in deciding on the range of items to be carried at the SERVMART.

The results in Table 1 show that, for some items, the number of orders per year with the economic-order-quantity models is actually greater than the number of orders with the simple models. However, the number of orders for the relatively inexpensive and high demand items is almost always reduced. This illustrates that the demand and cost characteristics should be considered in any decision concerning reorder quantities and reorder levels for items carried in an inventory. Indeed, the simple policies produce costs far exceeding the minimum possible costs primarily because they fail to consider much of the relevant information.

Also presented in Table 1 for Model 1 is the actual stockout protection for each of the selected items. That is, p_i is the probability that the total leadtime demand will not exceed the reorder level r_i. Notice that the stockout protection, although usually quite high, can vary quite a bit from item to item. Again, the item characteristics control the values obtained. In Model 2, the stockout protection was arbitrarily chosen to be 0.82. Note how reorder levels and the reorder quantities with Model 2 compare with those

of Model 1. With a more judicious choice of p, the comparisons could perhaps be made to appear even more favorable. We delay discussion of the imputed holding costs, also displayed in Table 2, to the next section which examines the impact of the budget constraint on average inventory investment.

VI. THE AVERAGE INVENTORY INVESTMENT BUDGET

The budget restriction on average inventory investment, in effect, imputes an inventory carrying rate. The imputed rate can be interpreted as that value of the inventory holding rate, I', which would be required to yield the same reorder levels and reorder quantities in the unconstrained minimization problem as produced by the budget constrained model - all other factors held the same. Using the average inventory investment constraint of 30 days stock, we found that the imputed holding rates ranged from a low of 1.30 to a high of 3.01 at the SERVMARTs that we studied. By comparison, the Navy typically uses values in the interval [0.10, 0.60] for inventory holding rates, especially for items of the type carried by SERVMARTs. This comparison gives some inkling that the budget restriction might be too severe. The magnitude of the imputed holding rate provides some insight as to the severity of the investment budget. Model 2 offers a simple and direct way to use the imputed holding rate to aid in the determination of the average stock investment budget. To be precise, if I' is the maximum holding rate acceptable to the system $(I' = I + \Theta)$, the budget which is required to yield I' as the imputed holding rate is given by

$$(6.1) \qquad B = \sum_{i=1}^{N} \left\{ \left(\frac{C_i \lambda_i (A + \pi \frac{W_i(r_i)}{M_i}}{2I'} \right)^{1/2} - C_i(\mu_i - r_i - W_i(r_i)) \right\}$$

For example, an average stock investment of \$6548, or roughly 60 days stock, is needed to drive the imputed holding rate at SERVMART J (200 item sample) down to 0.60. Accompanying the increase in budget from \$3257 (30 days stock) to \$6548 is a reduction in total system cost* of approximately 37%.

To point out more vividly the potential reduction in costs brought about by relaxing the budget constraint, the optimal reorder parameters and the minimum cost statistics at SERVMART J for the unconstrained minimization problem and for budget restrictions of 15 days stock, 30 days stock, 45 days stock and 60 days stock were determined. The effects of the different budgets in terms of system costs and performance are displayed in Table 3. As expected, increases in the budget cause decreases in the ordering costs, lost sales costs and the total system costs while holding costs increase. For the case where there was no limit on the budget (the unconstrained minimization problem) the average inventory investment is seen to be \$9020. Thus, the maximum budget should certainly not exceed \$9020.

Additional information about the impact of various budgets on total system cost is presented by Figure 1. The graph of the total system cost at SERVMART J vs. average inventory investment shows very large reductions in cost for relatively small increases in the budget when the budget is less than \$5000, but relatively small cost decreases when the budget is increased beyond \$5000. Thus, the marginal benefit of additional dollars is very high initially, but it approaches zero as the budget exceeds 60 days stock investment. For example, an increase in the budget from \$2000 to \$3000 creates a reduction in total cost per year from \$13,500 to \$9,250. On the other hand, a thousand dollar increase in budget from \$7000 to \$8000 only reduces annual costs from \$5350 to \$5200. In the former case, the thousand dollar increase is certainly

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*Total system cost is the sum of the ordering cost, the holding cost and the lost sales cost. It does not include inventory investments.

SERVMART J

(Sample of 200 Items Out of A Population of 2886 Items)

BUDGET CONSTRAINT	15 Days	30 Days	45 Days	60 Days	No Constraint
AVERAGE MONTHLY SALES	\$ 3280	\$3280	\$3280	\$3280	\$3280
NUMBER OF ORDERS	1611	747	480	346	243
ORDERING COST	\$16110	\$7470	\$4800	\$3460	\$2430
AVERAGE INVENTORY INVESTMENT	\$1634	\$3257	\$4890	\$6548	\$9020
AVERAGE STOCKOUT PROTECTION	0.72	0.86	0.91	0.95	0.96
LOST SALES COST	\$1880	\$ 334	\$ 132	\$ 56	\$ 28
HOLDING COST (I=0.3)	\$ 490	\$ 977	\$1467	\$1964	\$2706
IMPUTED HOLDING RATE ($I=I+\Theta$)	13.3	2.80	1.14	0.60	0.30
TOTAL SYSTEM COST	\$18476	\$8780	\$6400	\$5482	\$5162

TABLE 3

SERVMART J (200 ITEM SAMPLE FROM 2886 POPULATION)

TOTAL INVENTORY COST VS. BUDGET

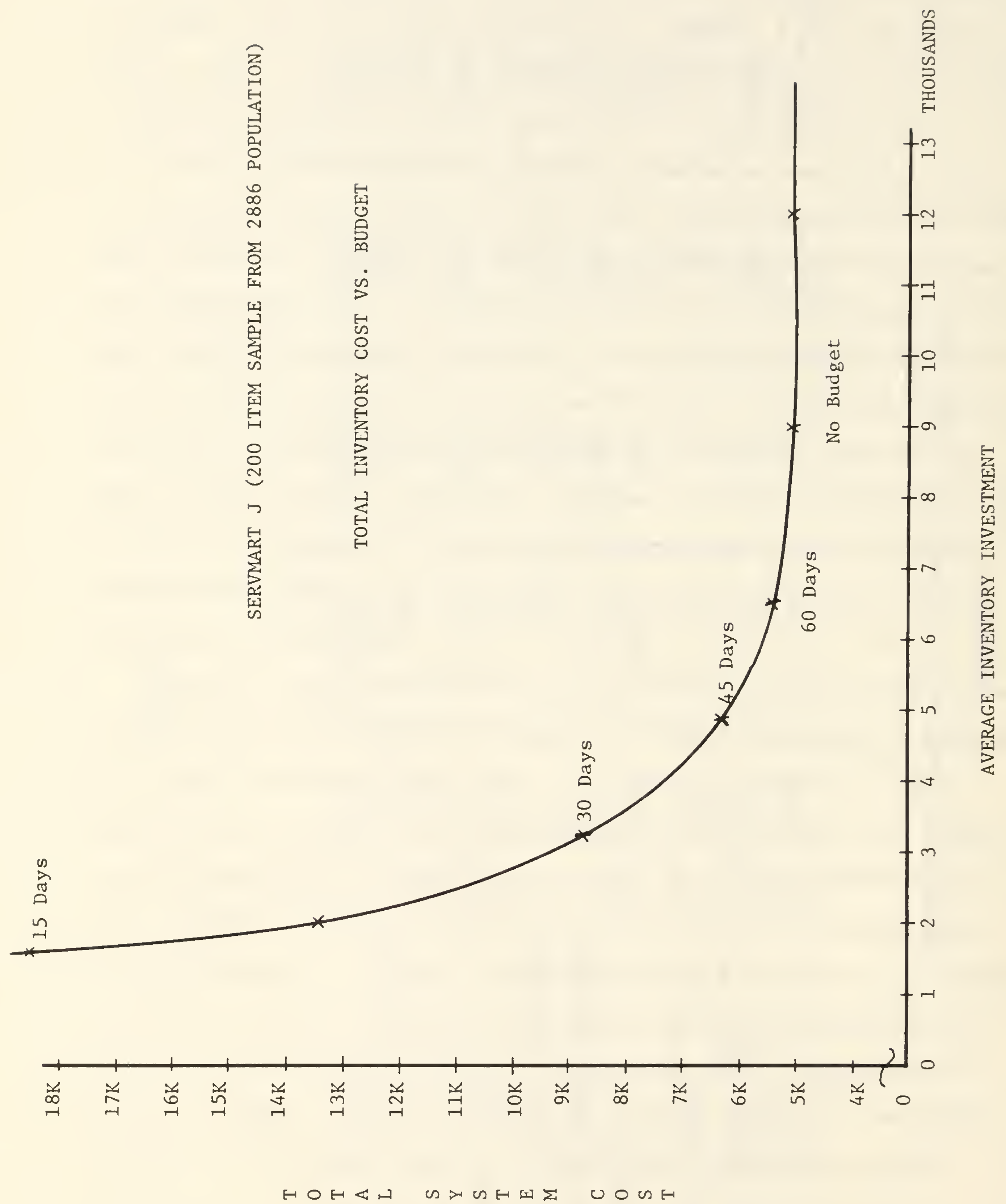

FIGURE 1

justified by the \$3750 cost savings. In the latter case, the decision to increase the budget is not so clear. Should an extra thousand dollars be invested to achieve a savings of \$150? To answer a question such as this, an inventory manager must determine the cost of investing extra money in SERVMART stock. This cost is simply a lost opportunity cost. For example, if the inventory manager must transfer funds from some other location where the funds are earning at a 10% rate of return to satisfy SERVMART investment needs, the cost of the additional thousand dollars is \$100. Thus, even in the latter case, the transfer of funds would be justified. Intelligent budget decisions require that the inventory manager be cognizant of the cost-tradeoffs available throughout the inventory system.

We are aware that many complex factors influence budget decisions. Such important factors as space constraints at the SERVMARTs or limits on units available for stockage might also enter into the decision about allowable inventory investment, and they are not considered in this paper. Nevertheless, the information which we have presented, and the type of analysis that we have discussed should be useful in making budget decisions.

VII. CONCLUSIONS

The EOQ models developed in this paper explicitly consider all available information about system costs and item characteristics. With the current 30-day stock investment constraint, the EOQ models reduce total system costs at the three SERVMARTs studied by amounts as high as 75% over the system costs resulting from two simple policies presently in use at some SERVMARTs. Although the two simple policies are easily understood and easily implemented, the very factor that makes them appealing also accounts for their major weakness - every item is treated the same. Viewing the inventory system as a feedback control system, it is readily apparent that any policy which ignores as much information as the simple policies examined here has little chance of comparing favorably with the best policies.

The savings achieved by the EOQ models result from reductions in the number of orders placed by the SERVMARTs on the NSCs. These reductions not only decrease total costs, but also decrease the workloads at both the SERVMARTs and the parent NSCs. Other benefits to the system such as better record accuracy and more rapid service should accrue from a decreased stock turnover rate.

Although the calculations required by the EOQ models are more involved than those required by the simpler policies, they are easily and quickly done by a computer. To aid in this regard, computer programs written in FORTRAN IV for both Model 1 and Model 2 are included in Appendix B and Appendix C, respectively. Comment cards are interspersed liberally throughout the programs to make them self-explanatory and easily used. In addition, each program contains a glossary of parameters and variables used in the program. Finally, both programs have instructions for utilizing the program to determine the required budget for a given maximum acceptable holding rate.

The amount of computer time required to determine all reorder levels and reorder quantities plus all relevant costs and summary information should not

exceed a few minutes for even the largest SERVMART. If Model 2 were used, the total computer time would probably be less than one minute. (For a 200 item sample, less than seven seconds were needed by the Naval Postgraduate School IBM 360/67.) Because Model 2 is simpler and faster, and it can be made to yield reorder values closely approximating those of Model 1, it will probably meet with better acceptance. However, it is suggested that Model 1 be used, at least on a sample of the SERVMARTs, to guide the inventory managers in judiciously choosing the stockout protection. Output from the program for Model 1 includes, for each item, the actual stockout protection p_i, the federal stock number, the unit price, the expected value of annual sales, the expected annual demand, Q_i, r_i, the average number of orders per year and the expected number of lost sales. Summary information includes annual sales, average inventory investment, total number of orders, total ordering cost, total lost sales cost, holding cost, imputed holding rate, total system cost and both weighted and unweighted averages of the p_i's. (The weighted average multiplies each p_i by the ratio of the value of annual sales for item i to the total value of annual sales.) With the exception of the p_i's, the output from Model 2 is almost identical to that of Model 1.

The examples that we investigated suggest that the budget constraint is too tight. A relaxation of the budget restriction to allow an average inventory investment of 60 days of stock was required to drive the inputed holding rates at all three SERVMARTs to the range 0.10 to 0.60. While it would be unwise to generalize these conclusions for all SERVMARTs, there is strong indication that a review of the budget restriction is justified. Some budget restriction is probably necessary to prevent SERVMART operations from becoming unmanageable; however, it appears that uniform budget restrictions, like uniform inventory policies, leave much room for improvement. While 30 days stock investment may be an appropriate budget for one SERVMART, it may be entirely inadequate for another. Again, item characteristics and system costs must be considered in the budget determination.

An examination of the items carried at three SERVMARTs in the San Diego area revealed that many items were carried which failed to have an average monthly demand of at least two units over a 12 month period as required by the NAVSUP directive [Ref. 1]. In addition, many other items would be eliminated by the stocking criterion developed in this paper. Those items are currently tying up investment money which could be used more economically on other items. In fact, many of those items actually cost the system additional dollars because they are carried at SERVMARTs. Perhaps the dollars freed by eliminating those items would by itself be sufficient to drive the imputed holding costs down to more reasonable levels. On the other hand, there are probably many items not carried at the SERVMARTs which would qualify under our stocking criterion. This might be the case in spite of the fact that some requirement of the NAVSUP directive might be violated. If economic considerations are to be the primary concern, we feel that the stocking criterion developed in this paper should override the $250 maximum unit price and the minimum yearly demand as required by the NAVSUP directive.

The sample calculations convince us that the use of our stocking criterion and either of the EOQ models for SERVMARTs will have a major impact on cost savings. If, in addition, investment budgets are reviewed as suggested, the potential cost savings - with a reduction in requisitioning workload and an improvement in customer service - is substantial.

APPENDIX A

The objective of Model 1 is to minimize the sum of total annual ordering costs, holding costs and lost sales costs at a given SERVMART subject to a budget constraint on the average inventory investment. The total average ordering cost per year is given by $A \sum_{i=1}^{N} \frac{\lambda_i}{Q_i}$ where N is the number of items carried at the given SERVMART. Let X_i be a random variable describing the leadtime demand for item i. By assumption, X_i has a normal distribution with mean μ_i and standard deviation σ_i. Then, if $X_i = x$, the number of units short during a cycle will be

$$\begin{cases} x - r_i & \text{if} \quad x > r_i \\ 0 & \text{if} \quad x \leq r_i \end{cases}$$

The expected number of units short per cycle is therefore

$$W_i(r_i) = \int_{r_i}^{\infty} (x - r_i) f_i(x)dx$$

Where f_i is the probability density function of X_i. On integrating and simplifying $W_i(r_i)$ we find that the expected number of units short per cycle is

$$W_i(r_i) = (\mu_i - r_i)\left(1 - F\left(\frac{r_i - \mu_i}{\sigma_i}\right)\right) + \sigma_i f\left(\frac{r_i - \mu_i}{\sigma_i}\right)$$

Where f and F are the probability function and cumulative distribution function, respectively, of a standard normal random variable. If M_i is the average number of units per customer demand, the expected lost sales cost per year is approximated by:

$$\pi \frac{\lambda_i}{Q_i} \frac{W_i(r_i)}{M_i} .$$

We approximate the average annual on-hand inventory by the simple average of S_i, the expected stock on hand just prior to the arrival of a shipment, and $S_i + Q_i$, the expected amount just after a shipment is received. Again, let x be the leadtime demand. The stock on hand just prior to receiving a shipment is then $\begin{cases} r_i - x & \text{if } x < r_i \\ 0 & \text{if } x \geq r_i \end{cases}$.

Consequently,

$$S_i = \int_0^{r_i} (r_i - x) f_i(x)dx$$

$$= \int_0^{\infty} (r_i - x) f_i(x)dx + \int_{r_i}^{\infty} (x - r_i) f_i(x)dx$$

$$S_i = r_i - \mu_i + W_i(r_i)$$

The average annual inventory holding cost for item i is then

$$IC_i \left(S_i + \frac{Q_i}{2}\right) = IC_i\left(r_i - \mu_i + W_i(r_i) + \frac{Q_i}{2}\right) .$$

The mathematical formulation of our problem becomes

$$\min \quad K = A \sum_{i=1}^{N} \frac{\lambda_i}{Q_i} + I \sum_{i=1}^{N} C_i\left(\frac{Q_i}{2} + r_i - \mu_i + W_i\right)$$

$$+ \pi \sum_{i=1}^{N} \frac{\lambda_i}{Q_i} \frac{W_i(r_i)}{M_i}$$

$$\text{subject to} \quad \sum_{i=1} C_i\left(\frac{Q_i}{2} + r_i - \mu_i + W_i(r_i)\right) \leq B \ .$$

To determine the optimal values of r_i and Q_i we form the Lagrangian function

$$L = K + \Theta \left[\sum_{i=1}^{N} C_i\left(\frac{Q_i}{2} + r_i - \mu_i + W_i(r_i)\right) - B \right]$$

where Θ is a Lagrange multiplier. We then solve the equations

$$\begin{cases} \dfrac{\partial L}{\partial Q_i} = 0 \\[2ex] \dfrac{\partial L}{\partial r_i} = 0 \\[2ex] \dfrac{\partial L}{\partial \Theta} = 0 \end{cases}$$

These equations give us

$$Q_i = \left[\frac{2\lambda_i (A + \pi \frac{W_i(r_i)}{M_i})}{(I + \Theta) C_i} \right]^{1/2}$$

$$1 - F\left(\frac{r_i - \mu_i}{\sigma_i}\right) = \frac{(I + \Theta) C_i Q_i}{(I+\Theta) C_i Q_i + \frac{\pi \lambda_i}{M_i}}$$

and

$$\sum_{i=1}^{N} C_i \left(\frac{Q_i}{2} + r_i - \mu_i + W_i(r_i)\right) = B \ .$$

APPENDIX B

```
C...........................................................................C
C..                                                                       ..C
C.........       MAJOR INPUT/OUTPUT PARAMETERS                  ..........C
C..                                                                       ..C
C..                                                                       ..C
C..   UPRICE(I)  UNIT PRICE OF ITEM I                                     ..C
C..   DEMAND(I)  EXPECTED ANNUAL UNITS DEMAND OF ITEM I                   ..C
C..   ISERV(I)   SERVMART IDENTIFICATION FOR ITEM I                       ..C
C..   VALUE(I)   EXPECTED ANNUAL DOLLAR SALES OF ITEM I                   ..C
C..   PRCB(I)    PROBABILITY OF NO LOST SALES FOR ITEM I                  ..C
C..   FSN(I)     FEDERAL STOCK NUMBER FOR ITEM I                          ..C
C..   STD(I)     STANDARD DEVIATION OF LEADTIME DEMAND                    ..C
C..                  FOR ITEM I                                           ..C
C..   M(I)       AVERAGE CUSTOMER DEMAND SIZE FOR ITEM I                  ..C
C..   Q(I)       REORDER QUANTITY OF ITEM I                               ..C
C..   R(I)       REORDER LEVEL OF ITEM I                                  ..C
C..   W(I)       EXPECTED NO. OF LOST SALES PER YEAR FOR                  ..C
C..                 ITEM I                                                ..C
C..   COSTHI      HOLDING COSTS COMPUTED USING INVENTORY                  ..C
C..                  CARRYING CHARGE I                                    ..C
C..   COSTLS      SYSTEM COSTS DUE TO LOST SALES                          ..C
C..   COSTOR      SYSTEM COSTS DUE TO SERVMART ORDERS                     ..C
C..   COSTZ2      HOLDING COSTS COMPUTED USING IMPUTED                    ..C
C..                 INVENTORY CARRYING CHARGE (I+THETA)                   ..C
C..   TCOSTI     TOTAL SYSTEM COSTS COMPUTED USING INVEN-                 ..C
C..                  TORY CARRYING CHARGE I                               ..C
C..   TCOSTZ     TOTAL SYSTEM COSTS COMPUTED USING IMPUT-                 ..C
C..                  ED INVENTORY CARRYING CHARGE(I+THETA)                ..C
C..   VALINV     VALUE OF AVERAGE INVENTORY INVESTMENT                    ..C
C..   VALMON     VALUE OF TOTAL EXPECTED ANNUAL DOLLAR                    ..C
C..                  SALES OF ALL ITEMS IN INVENTORY                      ..C
C..   AVVAL      VALUE OF TOTAL EXPECTED MONTHLY DOLLAR                   ..C
C..                  SALES OF ALL ITEMS IN INVENTORY                      ..C
C..   THETA      AN IMPUTED CARRYING RATE                                 ..C
C..   ORDER      EXPECTED TOTAL NUMBER OF ORDERS PER YEAR                 ..C
C..   DIFF       TOLERANCE FOR ACHIEVING BUDGET CONSTRAINT                ..C
C..   STEP       NO. OF SEARCHES FOR THETA NEEDED TO                      ..C
C..                  ACHIEVE THE BUDGET CONSTRAINT                        ..C
C..   CI         INVENTORY CARRYING RATE                                  ..C
C..   SC         STOCKOUT COST (COST OF A LOST SALE)                      ..C
C..   TL         PROCUREMENT LEADTIME FOR SERVMART ORDER                  ..C
C..   A          COST TO SYSTEM TO FILL ONE SERVMART ORDER                ..C
C..   B          BUDGET CONSTRAINT ON AVERAGE INVENTORY                   ..C
C..   N          NUMBER OF ITEMS IN SERVMART INVENTORY                    ..C
C..                                                                       ..C
C..                                                                       ..C
C...........................................................................C
C...........................................................................C
C..                                                                       ..C
C.........       DIMENSION PARAMETERS TO SIZE OF                ..........C
C.........       INVENTORY FOR STORAGE OF DATA                  ..........C
C..                                                                       ..C
C...........................................................................C
      REAL MLTDEM
      REAL * 8 FSN
      DIMENSION ISERV(200),FSN(200),UPRICE(200),VALUE(200),
     1M(200),STD(200),Q(200),R(200),ORDS(200),W(200),
     2DEMAND(200),PROB(200)
C...........................................................................C
C..                                                                       ..C
C...............          READ INPUT DATA          ......................C
C..                                                                       ..C
C...........................................................................C
      READ(5,1000)B,SC,CI,TL,A,DIFF,N
 1000 FORMAT(F10.2,F5.2,F4.3,F4.3,F6.2,F6.2,I5)
      VD=B+DIFF
      VI=B-DIFF
```

```
C.............................................................C
C..                                                         ..C
C........      INITIALIZE KEY OUTPUT PARAMETERS       ........C
C..                                                         ..C
C.............................................................C
      COSTHI=0.0
      COSTZ2=0.0
      VALINV=0.0
      COSTLS=0.0
      ORDER=0.0
      VALMON=0.0
      THETA=0.0
      STEP=0.0
      MARK1=1
      PRC=0.0
      ZOOM=0.0
      DO 10 I=1,N
      READ(5,1100)ISERV(I),FSN(I),UPRICE(I),VALUE(I),M(I),
     2STD(I)
 1100 FORMAT(I2,F11.0,F5.2,F7.2,I3,F6.2)
      DEMAND(I)=VALUE(I)/UPRICE(I)
C.............................................................C
C..                                                         ..C
C.........      COMPUTE VALUE OF ANNUAL SALES         .........C
C..                                                         ..C
C.............................................................C
      VALMON=VALMON+VALUE(I)
   10 CONTINUE
C.............................................................C
C..                                                         ..C
C.....   SET THE IMPUTED INVENTORY CARRYING CHARGE      .....C
C..                                                         ..C
C.............................................................C
  105 Z2=CI+THETA
      VALIN=0.0
C.............................................................C
C..                                                         ..C
C...    COMPUTE REORDER QUANTITIES AND REORDER LEVELS      ...C
C..                                                         ..C
C.............................................................C
      DO 20 I=1,N
  106 Z1=CI*UPRICE(I)
      QANTY=SQRT(2.0*DEMAND(I)*A/Z1)
      IQ=QANTY
      Q(I)=QANTY
      VAR=(STD(I))**2
  100 UP=UPRICE(I)*Q(I)*Z2
      DH=UP/(UP+SC*DEMAND(I)/M(I))
      P=1.0-DH
      CALL NDTRI(P,X,D,IER)
      MLTDEM=DEMAND(I)*TL
      R(I)=MLTDEM+STD(I)*X
      W(I)=STD(I)*D-(R(I)-MLTDEM)*DH
      Q(I)=SQRT((2.0*DEMAND(I)*(A+SC*W(I)/M(I)))/(UPRICE(I)*
     3Z2))
      IIQ=Q(I)
      DUMB=IIQ-IQ
      QNTY=ABS(DUMB)
      IF(QNTY.GE.1.0)GO TO 101
      IF(Q(I).LT.1.0)Q(I)=1.0
C.............................................................C
C..                                                         ..C
C....    COMPUTE VALUE OF AVE. INVENTORY INVESTMENT        ....C
C..                                                         ..C
C.............................................................C
      DIAL=UPRICE(I)*(Q(I)/2.0+R(I)-MLTDEM+W(I))
      VALIN=VALIN+DIAL
   20 CONTINUE
```

```
C...............................................................C
C..                                                           ..C
C..    TO DETERMINE THE BUDGET FOR THE INPUT INVENTORY       ..C
C..  CARRYING RATE CI, REMOVE C FROM THE FOLLOWING CARD       ..C
C..                                                           ..C
C...............................................................C
C     GO TO 600
C...............................................................C
C..                                                           ..C
C.......           CHECK IF VALUE OF AVE.               ........C
C.......       INVENTORY MEETS BUDGET CONSTRAINT        ........C
C..                                                           ..C
C...............................................................C
      IF(VALIN.LE.VD.AND.THETA.EQ.0.0) GO TO 600
      IF(VALIN.LE.VD.AND.VALIN.GE.VI) GO TO 600
      IF(VALIN.GT.VD) GO TO 601
      IF(VALIN.LT.VI) GO TO 602
  600 DO 30 I=1,N
C...............................................................C
C..                                                           ..C
C.............          ROUND Q(I) AND R(I)      ..............C
C..                                                           ..C
C...............................................................C
      NQ=Q(I)
      Q(I)=NQ
      IR=R(I)+1.0
      R(I)=IR
C...............................................................C
C..                                                           ..C
C......           COMPUTE VALUE OF AVE.                ........C
C......      INVENTORY WITH Q(I) AND R(I) ROUNDED        ......C
C..                                                           ..C
C...............................................................C
      MLTDEM=DEMAND(I)*TL
      X=(R(I)-MLTDEM)/STD(I)
      CALL NDTR(X,P,D)
      DH=1.0-P
      PROB(I)=P
      W(I)=STD(I)*D-(R(I)-MLTDEM)*DH
      IF(W(I).LT.0.0) W(I)=0.0
      COOR=UPRICE(I)*(Q(I)/2.0+R(I)-MLTDEM+W(I))
      VALINV=VALINV+COOR
C...............................................................C
C..                                                           ..C
C.....    COMPUTE EXPECTED NO. OF ORDERS PER YEAR          .....C
C..                                                           ..C
C...............................................................C
  201 ORDS(I)=DEMAND(I)/Q(I)
      ORDER=ORDER+ORDS(I)
C...............................................................C
C..                                                           ..C
C..... COMPUTE SYSTEM COSTS DUE TO HOLDING CHARGE I         .....C
C..                                                           ..C
C...............................................................C
      COSTHI=COSTHI+CI*COOR
C...............................................................C
C..                                                           ..C
C.. COMPUTE SYSTEM COSTS DUE TO IMPUTED CARRYING CHARGE      ..C
C..                                                           ..C
C...............................................................C
      COSTZ2=COSTZ2+COOR*Z2
C...............................................................C
C..                                                           ..C
C.......    COMPUTE SYSTEM COSTS DUE TO LOST SALES        ......C
C..                                                           ..C
C...............................................................C
      COSTLS=COSTLS+ORDS(I)*W(I)*SC
```

```
C...............................................................C
C..                                                           ..C
C..    COMPUTE WEIGHTED AVEFAGE OF PRCBABILITY CF NO        ....C
C.. LOST SALES (WEIGHTED BY PERCENTAGE OF ANNUAL SALES)       ..C
C..                                                           ..C
C...............................................................C
      PRC=PRO+PROB(I)*VALUE(I)/VALMON
C...............................................................C
C..                                                           ..C
C.........       COMPUTE UNWEIGHTED AVERAGE OF          .........C
C..........       PROBABILITY OF NO LOST SALES          .........C
C..                                                           ..C
C...............................................................C
      ZCCM=ZOCM+PROB(I)/N
   30 CONTINUE
C...............................................................C
C..                                                           ..C
C....    COMPUTE SYSTEM COSTS DUE TO SERVMART ORDERS         ....C
C..                                                           ..C
C...............................................................C
      CCSTOR=ORDER*A
C...............................................................C
C..                                                           ..C
C.......     COMPUTE TOTAL SYSTEM COSTS UNDER I         .......C
C..                                                           ..C
C...............................................................C
      TCCSTI=COSTOR+COSTHI+COSTLS
C...............................................................C
C..                                                           ..C
C....     COMPUTE TOTAL SYSTEM COSTS UNCER I+THETA           ....C
C..                                                           ..C
C...............................................................C
      TCOSTZ=COSTOR+COSTZ2+COSTLS
      WRITE(6,1500)
 1500 FCRMAT('1',3X,'SERVMART',8X,'FSN',10X,'UPRICE',7X,
     1'VALUE',7X,'DEMANDS',8X,'Q',11X,'R',8X,'NC.CRDERS',5X,
     2'LCST SALES',6X,'P')
C...............................................................C
C..                                                           ..C
C...........       PRINT OUTPUT INFORMATION           ...........C
C..                                                           ..C
C...............................................................C
      CC 40 I=1,N
      W(I)=W(I)*CRDS(I)
      WRITE(6,2000)ISERV(I),FSN(I),UPRICE(I),VALUE(I),
     1DEMAND(I),Q(I),R(I),ORDS(I),W(I),PROB(I)
 200C FCRMAT(' ',6X,I2,5X,F12.0,6X,F6.2,6X,F7.2,7X,F6.1,7X,
     1F5.1,6X,F5.1,7X,F6.1,11X,F5.2,4X,F5.3)
   40 CCNTINUE
      AVVAL=VALMON/12.0
      WRITE(6,2100)VALMON,AVVAL,B
 2100 FCRMAT('1',3X,'ANNUAL SALES',F12.2,15X,'AVE.MO.SALES',
     1F12.2,15X,'BUDGET CONSTRAINT',F12.2)
      WRITE(6,2200)ORDER,VALINV
 220C FCRMAT('0',3X,'TOTAL NC. ORDERS',F8.1,15X,
     1'AVE. INVENTORY INVESTMENT',F12.2)
      WRITE(6,2300)STEP,THETA,Z2
 230C FORMAT('0',3X,'NO.STEPS TO DETERMINE OPTIMUM THETA',
     1F6.1,10X,'OPTIMUM THETA',F7.4,10X,'IMPUTED CARRYING ',
     2'CHARGE',F7.4)
      WRITE(6,2400)COSTCR,COSTLS
 2400 FCRMAT('0',3X,'ORDER COSTS',F10.2,10X,'LCST SALES ',
     1'CCSTS',F10.2)
      WRITE(6,2500)COSTHI,COSTZ2
 2500 FORMAT('0',3X,'HOLDING COSTS UNDER I',F1C.2,10X,
     1'HOLDING COSTS UNDER (I+THETA)',F10.2)
      WRITE(6,2600)TCOSTI,TCOSTZ
 2600 FCRMAT('0',3X,'TOTAL SYSTEM COSTS UNDER I',F12.2,10X,
     1'TOTAL SYSTEM COSTS UNDER (I+THETA)',F12.2)
      WRITE(6,2700) PRO,ZOOM
 2700 FCRMAT('0',3X,'WEIGHTEC AVERAGE CF PROBABILITY OF NO',
     1' LOST SALES',F8.3,10X,'UNWEIGHTED AVERAGE CF PROBAB',
```

```
     2'ILITY OF NO LOST SALES',F8.3)
      GC TO 5C0
C..........................................................C
C..                                                      ..C
C.......      CORRECTING STEPS IF INVENTCRY VALUE    ......C
C.......      IS GREATER THAN BUDGET TOLERANCE       ......C
C..                                                      ..C
C..........................................................C
  601 THET1=THETA
      VAL1=VALIN
      IF(MARK1.EQ.1) GO TO 700
      VAL3=ABS(VAL1-VAL2)
      THET=ABS(THET1-THET2)
      VAL4=ABS(VALIN-B)
      CHANGE=THET*VAL4/VAL3
      THETA=THETA+CHANGE
      STEP=STEP+1.0
      GC TO 105
C..........................................................C
C..                                                      ..C
C.......      CORRECTING STEPS IF INVENTORY VALUE    ......C
C.......        IS LESS THAN BUDGET TOLERANCE        ......C
C..                                                      ..C
C..........................................................C
  602 THET2=THETA
      VAL2=VALIN
      VAL3=ABS(VAL1-VAL2)
      THET=ABS(THET1-THET2)
      VAL4=ABS(VALIN-B)
      CHANGE=THET*VAL4/VAL3
      THETA=THETA-CHANGE
      MARK1=0
      STEP=STEP+1.0
      GC TO 105
  700 THETA=THETA+1.0
      STEP=STEP+1.0
      GC TO 105
  101 IC=Q(I)
      GC TO 100
  500 STCP
      ENC

      SUBROUTINE NDTRI(P,X,D,IE)
      X=.99999E+74
      IE=0
      D=X
      IF(P)1,4,2
 1    IE=-1
      GC TO 12
 2    IF(P-1.0)7,5,1
 4    X=-0.999999E+74
 5    C=0.0
      GC TO 12
 7    D=P
      IF(D-0.5)9,9,8
 8    D=1.0-D
 9    T2=ALOG(1.0/(D*D))
      T=SQRT(T2)
      X=T-(2.515517+0.802853*T+0.010328*T2)/(1.0+1.432788*T+
     10.189269*T2+0.001308*T*T2)
      IF(P-0.5)10,10,11
 1C   X=-X
 11   C=0.3989423*EXP(-X*X/2.0)
 12   RETURN
      END
```

```
      SUBROUTINE NDTR(X,P,D)
      AX=ABS(X)
      T=1.0/(1.0+.2316419*AX)
      D=0.3989423*EXP(-X*X/2.0)
      P=1.0-D*T*((((1.330274*T-1.821256)*T+1.781478)*T-
     10.3565638)*T+0.3193815)
      IF(X)1,2,2
    1 P=1.0-P
    2 RETURN
      END
```

APPENDIX C

```
C.......................................................................C
C..                                                                   ..C
C.........      MAJOR INPUT/OUTPUT PARAMETERS                 .........C
C..                                                                   ..C
C..                                                                   ..C
C..   UPRICE(I)   UNIT PRICE OF ITEM I                                ..C
C..   DEMAND(I)   EXPECTED ANNUAL UNITS DEMAND OF ITEM I              ..C
C..   ISERV(I)    SERVMART IDENTIFICATION FOR ITEM I                  ..C
C..   VALUE(I)    EXPECTED ANNUAL DOLLAR SALES OF ITEM I              ..C
C..   FSN(I)      FEDERAL STOCK NUMBER FOR ITEM I                     ..C
C..   STD(I)      STANDARD DEVIATION OF LEADTIME DEMAND               ..C
C..                  FOR ITEM I                                       ..C
C..   M(I)        AVERAGE CUSTOMER DEMAND SIZE FOR ITEM I             ..C
C..   Q(I)        REORDER QUANTITY OF ITEM I                          ..C
C..   R(I)        REORDER LEVEL OF ITEM I                             ..C
C..   W(I)        EXPECTED NO. OF LOST SALES PER YEAR FOR             ..C
C..                 ITEM I                                            ..C
C..   COSTLS       SYSTEM COSTS DUE TO LOST SALES                     ..C
C..   COSTOR       SYSTEM COSTS DUE TO SERVMART ORDERS                ..C
C..   COSTTI      SYSTEM COSTS DUE TO CARRYING RATE BASED             ..C
C..                 ON THE IMPUTED VALUE                              ..C
C..   TCOSTH      TOTAL SYSTEM COSTS COMPUTED WITH A                  ..C
C..                 CARRYING RATE OF 0.30                             ..C
C..   TCOSTI      TOTAL SYSTEM COSTS COMPUTED WITH THE                ..C
C..                 IMPUTED CARRYING RATE                             ..C
C..   VALINV      VALUE OF AVERAGE INVENTORY INVESTMENT               ..C
C..   VALMON      VALUE OF TOTAL EXPECTED ANNUAL DOLLAR               ..C
C..                  SALES OF ALL ITEMS IN INVENTORY                  ..C
C..   AVVAL       VALUE OF TOTAL EXPECTED MONTHLY DOLLAR              ..C
C..                  SALES OF ALL ITEMS IN INVENTORY                  ..C
C..   ORDER       EXPECTED TOTAL NUMBER OF ORDERS PER YEAR            ..C
C..   THETA       VALUE OF THE IMPUTED CARRYING RATE                  ..C
C..   COSTH       SYSTEM COSTS DUE TO CARRYING RATE OF 0.3            ..C
C..   SC          STOCKOUT COST (COST OF A LOST SALE)                 ..C
C..   TL          PROCUREMENT LEADTIME FOR SERVMART ORDER             ..C
C..   A           COST TO SYSTEM TO FILL ONE SERVMART ORDER           ..C
C..   B           BUDGET CONSTRAINT ON AVERAGE INVENTORY              ..C
C..   N           NUMBER OF ITEMS IN SERVMART INVENTORY               ..C
C..   P           PROBABILITY THAT THE SERVMART WILL NOT              ..C
C..                 INCUR A LOST SALE                                 ..C
C..                                                                   ..C
C..                                                                   ..C
C..                                                                   ..C
C.......................................................................C
C.......................................................................C
C..                                                                   ..C
C.........      DIMENSION PARAMETERS TO SIZE OF               .........C
C.........      INVENTORY FOR STORAGE OF DATA                 .........C
C..                                                                   ..C
C.......................................................................C
      REAL MLTDEM
      REAL * 8 FSN
      DIMENSION ISERV(200),FSN(200),UPRICE(200),VALUE(200),
     1M(200),STD(200),Q(200),R(200),ORDS(200),W(200),
     2DEMAND(200)
C.......................................................................C
C..                                                                   ..C
C..............         READ INPUT DATA          ......................C
C..                                                                   ..C
C.......................................................................C
      READ(5,1000)N,B,TL,SC,A,P
 1000 FORMAT(I5,F10.2,F5.3,F5.2,F5.2,F5.4)
C.......................................................................C
C..                                                                   ..C
C.........     INITIALIZE KEY OUTPUT PARAMETERS                .........C
C..                                                                   ..C
C.......................................................................C
      VALINV=0.0
      ORDER=0.0
      VALMON=0.0
```

```
      BREW=0.0
      DENOM=0.0
      COSTTI=0.0
      COSTH=0.0
      COSTLS=0.0
      TCOSTH=0.0
      TCOSTI=0.0
      DO 10 I=1,N
      READ(5,1100)ISERV(I),FSN(I),UPRICE(I),VALUE(I),M(I),
     2STD(I)
 1100 FORMAT(I2,F11.0,F5.2,F7.2,I3,F6.2)
      DEMAND(I)=VALUE(I)/UPRICE(I)
   10 CONTINUE
C............................................................C
C..                                                        ..C
C............    COMPUTE REORDER LEVEL    ...................C
C..                                                        ..C
C............................................................C
      CALL NDTRI(P,X,D,IER)
      DO 20 I=1,N
      VAR=(STD(I))**2
      MLTDEM=DEMAND(I)*TL
      R(I)=MLTDEM+X*STD(I)
      W(I)=STD(I)*D+(1.0-P)*(MLTDEM-R(I))
      COMA=A+SC*W(I)/M(I)
      BREW=BREW+UPRICE(I)*(MLTDEM-R(I)-W(I))
      DENOM=DENOM+SQRT(DEMAND(I)*UPRICE(I)*COMA)
   20 CONTINUE
C............................................................C
C..                                                        ..C
C..    TO DETERMINE THE BUDGET FOR THE INPUT INVENTORY     ..C
C..  CARRYING RATE THETA, INPUT A VALUE FOR THETA BELOW    ..C
C..       AND REMOVE C FROM THE FOLLOWING SIX CARDS        ..C
C..                                                        ..C
C............................................................C
C     THETA=
C     B=0.7071*DENOM/THETA-BREW
C     WRITE(6,9999) B,THETA
C9999 FORMAT('1',3X,'BUDGET DETERMINED FOR INPUT CARRYING ',
C    1'RATE THETA',F10.2,5X,'VALUE OF THETA',F6.3)
C     GO TO 500
C............................................................C
C..                                                        ..C
C....     COMPUTE IMPUTED INVENTORY CARRYING RATE     .......C
C..                                                        ..C
C............................................................C
      THETA=(DENOM/(1.414214*(B+BREW)))**2
      DO 30 I=1,N
C............................................................C
C..                                                        ..C
C...........      COMPUTE REORDER QUANTITY     ..............C
C..                                                        ..C
C............................................................C
      FOAM=SQRT(DEMAND(I)/UPRICE(I))
      OLY=SQRT(A+SC*W(I)/M(I))
      SNUM=2.0*FOAM*OLY*(B+BREW)
      QTY=SNUM/DENOM
      IF(QTY.LT.1.0) QTY=1.0
C............................................................C
C..                                                        ..C
C.............      ROUND Q(I) AND R(I)      ................C
C..                                                        ..C
C............................................................C
      NQ=QTY
      Q(I)=NQ
      IR=R(I)+1.0
      R(I)=IR
C............................................................C
C..                                                        ..C
C..........      COMPUTE VALUE OF AVE. INVENTORY     ........C
C..                                                        ..C
C............................................................C
```

```
      MLTDEM=DEMAND(I)*TL
      DIAL=UPRICE(I)*(Q(I)/2.0+R(I)-MLTCEM+W(I))
      W(I)=STD(I)*D+(1.0-P)*(MLTDEM-R(I))
      IF(W(I).LT.0.0) W(I)=0.0
      VALINV=VALINV+DIAL
C..............................................................C
C..                                                          ..C
C.........      COMPUTE VALUE OF ANNUAL SALES        ..........C
C..                                                          ..C
C..............................................................C
      VALMON=VALMON+VALUE(I)
C..............................................................C
C..                                                          ..C
C.....    COMPUTE EXPECTED NO. OF ORDERS PER YEAR         .....C
C..                                                          ..C
C..............................................................C
      ORDS(I)=DEMAND(I)/Q(I)
      CRCER=ORDER+ORDS(I)
C..............................................................C
C..                                                          ..C
C......    COMPUTE SYSTEM COSTS DUE TO LCST SALES         ......C
C..                                                          ..C
C..............................................................C
      CCSTLS=COSTLS+ORDS(I)*W(I)*SC
C..............................................................C
C..                                                          ..C
C..  COMPUTE SYSTEM COSTS DUE TO IMPUTEC CARRYING RATE       ..C
C..                                                          ..C
C..............................................................C
      CCSTTI=COSTTI+THETA*DIAL
C..............................................................C
C..                                                          ..C
C...........       COMPUTE SYSTEM COSTS DLE         ...........C
C.......       TO ASSUMED CARRYING RATE OF 0.30       ..........C
C..                                                          ..C
C..............................................................C
      CCSTH=CCSTH+0.30*DIAL
   30 CCNTINUE
C..............................................................C
C..                                                          ..C
C....   COMPUTE SYSTEM COSTS DUE TC SERVMART CRCERS       ....C
C..                                                          ..C
C..............................................................C
      CCSTOR=ORDER*A
      WRITE(6,1500)
 1500 FORMAT('1',3X,'SERVMART',8X,'FSN',10X,'UPRICE',7X,
     1'VALUE',7X,'DEMANDS',8X,'Q',11X,'R',8X,'NC.CRDERS',5X,
     2'LCST SALES')
C..............................................................C
C..                                                          ..C
C...........      COMPUTE TOTAL SYSTEM COSTS         ..........C
C...........      WITH IMPUTED CARRYING RATE         ..........C
C..                                                          ..C
C..............................................................C
      TCOSTI=COSTOR+COSTTI+COSTLS
C..............................................................C
C..                                                          ..C
C......          COMPUTE TOTAL SYSTEM CCSTS              ......C
C......      WITH ASSUMED CARRYING RATE OF 0.30           ......C
C..                                                          ..C
C..............................................................C
      TCCSTH=CCSTCR+COSTH+COSTLS
C..............................................................C
C..                                                          ..C
C...........        PRINT OUTPUT INFORMATION          .........C
C..                                                          ..C
C..............................................................C
      DC 40 I=1,N
      W(I)=W(I)*ORDS(I)
      WRITE(6,2000)ISERV(I),FSN(I),UPRICE(I),VALLE(I),
     1DEMAND(I),Q(I),R(I),ORDS(I),W(I)
 2000 FCRMAT(' ',6X,I2,5X,F12.0,6X,F6.2,6X,F7.2,7X,F6.1,7X,
```

```
     1F5.1,6X,F5.1,7X,F6.1,11X,F5.2)
  40 CONTINUE
     AVVAL=VALMON/12.0
     WRITE(6,2100)VALMON,AVVAL,B
2100 FORMAT('1',3X,'ANNUAL SALES',F12.2,15X,'AVE.MO.SALES',
    1F12.2,15X,'BUDGET CONSTRAINT',F12.2)
     WRITE(6,2200)ORDER,VALINV
2200 FORMAT('0',3X,'TOTAL NO. ORDERS',F8.1,15X,
    1'AVE. INVENTORY INVESTMENT',F12.2)
     WRITE(6,2300)THETA
2300 FORMAT('0',3X,'IMPUTED INVENTORY CARRYING RATE',F8.4)
     WRITE(6,2400)COSTOR,COSTLS
2400 FORMAT('0',3X,'ORDER COSTS',F10.2,10X,'LOST SALES ',
    1'COSTS',F10.2)
     WRITE(6,2500) COSTTI,COSTH
2500 FORMAT('0',3X,'HOLDING COSTS WITH IMPUTED CARRYING ',
    1'RATE',F10.2,10X,'HOLDING COSTS WITH CARRYING ',
    2'RATE ASSUMED TO BE 0.30',F10.2)
     WRITE(6,2600)TCOSTI
2600 FORMAT('0',3X,'TOTAL SYSTEM COSTS WITH IMPUTED ',
    1'CARRYING RATE',F12.2)
     WRITE(6,2650)TCOSTH
2650 FORMAT('0',3X,'TOTAL SYSTEM COSTS WITH ASSUMED ',
    1'CARRYING RATE OF 0.30',F12.2)
     WRITE(6,2700)P
2700 FORMAT('0',3X,'PROTECTION AGAINST LOST SALES --P',F8.4
    1)
     STOP
     END

     SUBROUTINE NDTRI(P,X,D,IE)
     X=.99999E+74
     IE=0
     D=X
     IF(P)1,4,2
1    IE=-1
     GO TO 12
2    IF(P-1.0)7,5,1
4    X=-0.999999E+74
5    D=0.0
     GO TO 12
7    D=P
     IF(D-0.5)9,9,8
8    D=1.0-D
9    T2=ALOG(1.0/(D*D))
     T=SQRT(T2)
     X=T-(2.515517+0.802853*T+0.010328*T2)/(1.0+1.432788*T+
    10.189269*T2+0.001308*T*T2)
     IF(P-0.5)10,10,11
10   X=-X
11   D=0.3989423*EXP(-X*X/2.0)
12   RETURN
     END
```

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13. ABSTRACT

Inventory policies for the control of items carried by the Naval Supply Centers at their retail self-service stores (SERVMARTS) are developed. The reorder-level, reorder-quantity procedures minimize ordering, holding and stockout costs subject to constraints on inventory investment and stockout risk.

Examples are presented for random samples from three SERVMARTS in the San Diego area and comparisons are made with two policies presently in use. The comparisons show a large reduction in the number of orders placed per year with a reduction in total system costs. Also included are recommended procedures for determining both the budget for inventory investment and the range of items carried at the SERVMARTS.

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Economic Order Quantity						
SERVMART						
Cost Effectiveness						
Budget Determination						
Range Determination						

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